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A survey of formaldehyde in high galactic latitudes

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Summary. We report the discovery of formaldehyde H_2CO in four out of 15 CO-clouds observed in high galactic latitudes. For one of these we present a velocity integrated formaldehyde map. The clouds are clearly connected to CO-clouds described by de Vries et al. (1986), to Lynds bright and dark nebulae (Lynds, 1963) and to the galactic infrared cirrus (Low et al., 1984). The distribution of CO and H_2CO clouds is compared. The depths of the 1_{10-11} H_2CO lines show no correlation to the integrated $J = 1 \rightarrow 0$ ^{12}CO line intensities.

Key words: molecular clouds: formaldehyde – dust: molecular clouds – high latitude

1. Introduction

Although the high latitude clouds were already catalogued in 1962 (Lynds, 1962) they became an object of special interest only recently. Goerigk et al. (1983) were the first who detected ^{12}CO in one of these clouds, the so called Draco Nebula. Mebold et al. (1985) reported the discovery of formaldehyde in the same cloud. The large distance of that cloud ($z > 500$ pc, Goerigk and Mebold, 1986) is proof that molecules exist far from the galactic plane. That a significant amount of CO molecules is connected with the so called infrared cirrus (Low et al., 1984) was reported by Magnani et al. (1985) and Keto and Myers (1986). In the present paper we show that some of the high latitude clouds are also connected to formaldehyde clouds.

We observed the strongest CO concentrations described by de Vries et al. (1986) in the Ursa Major region and in the region near the north equatorial pole (Heithausen et al. 1986), hereafter the Polar Clouds, in the 6.2 cm line of formaldehyde with the 100 m telescope in Effelsberg.

The line is always seen in absorption against the microwave background since the galactic continuum in these regions is negligible. The distribution of the H_2CO integrated line intensities is different to the one of ^{12}CO. We find strong CO clumps with no formaldehyde and weak CO clumps with significant H_2CO absorption.

2. The observations

The H_2CO observations were made between March 1984 and May 1986 with the 100 m telescope in Effelsberg, which has a beamsize of 3 arcmin and a main beam efficiency of 0.7 at 4.82966 GHz. The spectra were obtained with a single channel cooled parametric amplifier which had a system temperature between 35 K to 60 K depending on weather conditions. We used the 1024 channel autocorrelation spectrometer which was split into two banks with 512 channels each. The bandwidth was 1563 KHz, leading to a velocity resolution of $0.19\,\mathrm{km\,s^{-1}}$. The integration time was at least two hours for each spectrum resulting in an rms noise of about 16 mK (T_A). In case a line was detected, the integration time was increased so that the signal-to-noise-ratio was at least 3 (cf. Table 1).

The spectra were observed with a frequency switching technic having the signal in the signal- and in the reference-band. The lines were calibrated using the H_2CO line of W3 which was observed in the beginning and in the end of each session assuming a line antenna temperature of -4.6 K and -2.5 K and full width at half power of $2\,\mathrm{km\,s^{-1}}$ for both the $v_{\mathrm{LSR}} = -40.1\,\mathrm{km\,s^{-1}}$ and $-38.5\,\mathrm{km\,s^{-1}}$ lines (Wilson et al., 1976).

The $J = 1 \rightarrow 0$ transition at 115 GHz of the ^{12}CO molecule was observed with the Columbia 1.2 m telescope using an SIS receiver and a 256 channel spectrometer. The spectra were integrated to an rms noise of 0.1 K, the velocity resolution was $0.65\,\mathrm{km\,s^{-1}}$. The beamwidth was 8.′7. Observations were carried out in a rectangular grid of 7.′5 spacing and an overall size as indicated in Fig. 2 of de Vries et al. (1986). (For detailed information about the calibration see R.S. Cohen et al., 1986).

3. The results and discussion

In Table 1 we list the line parameters for all positions where we searched for H_2CO, except for cloud 13 where we only list the values for the three strongest clumps. The detection limit is about 16 mK (T_A), except for cloud 3 and 10 where it is improved to 8 mK.

The clouds are numbered by increasing longitude (column 1). Columns 2 and 3 give the galactic longitude and latitude of the observed positions.

Columns 4–9 give the line parameters and their respective uncertainties for the H_2CO line as obtained from gaussian analysis. T_A is the antenna line temperature, Δv is the full width at half maximum, v is the center velocity of the line with respect to the local standard of rest (LSR).

Column 10 gives the velocity integrated antenna temperature of the ^{12}CO line defined by

$$W(\mathrm{CO}) = \int T_A^* \cdot dv$$

where T_A^* is defined according to Kutner and Ulich (1981).

Table 1. Line parameters for the formaldehyde spectra

Cloud No.	l	b	T_A (mK)	dT	Δv (km s^{-1})	$d\Delta v$	v (km s^{-1})	dv	W(CO) (K km s^{-1})
1	123.500	31.750	−26	7	0.9	0.3	2.8	0.1	1.6
2	123.950	30.000	< −16		–		–		1.6
3	124.492	30.595	< −16		–		–		2.8
	125.100	30.300	< −8		–		–		4.4
	125.601	30.142	< −16		–		–		2.0
4	124.700	29.380	< −16		–		–		3.6
5	124.750	29.360	< −16		–		–		3.6
6	125.240	32.570	< −16		–		–		1.6
7	126.595	32.500	−42	6	1.9	0.3	1.8	0.1	2.4
	126.620	32.475	−41	7	1.7	0.4	2.0	0.1	2.4
	126.620	32.500	−48	7	1.2	0.2	2.0	0.1	2.4
	126.620	32.525	−46	6	2.4	0.4	2.2	0.1	2.4
	126.620	32.550	< −16		–		–		2.0
	126.645	32.500	−62	9	1.0	0.2	2.1	0.7	2.4
8	140.750	39.750	< −16		–		–		1.2
9	141.270	34.380	< −16		–		–		2.4
10	143.027	38.489	< −8		–		–		4.0
11	146.023	41.296	−32	4	1.3	0.2	4.1	0.7	4.8
12	146.280	39.600	< −16		–		–		3.5
13	146.750	40.650	−114	9	1.3	0.1	3.1	0.1	5.2
	146.850	40.675	−104	6	1.0	0.1	3.6	0.3	5.2
	147.250	40.725	−81	11	0.8	0.1	3.7	0.6	5.2
14	147.600	36.900	< −16		–		–		1.2
15	148.400	38.400	< −16		–		–		2.8

Notes: l and b are the galactic coordinates of the observed positions, T_A is the line antenna temperature, Δv the fullwidth to half maximum and v the center velocity of the line as obtained from a single gaussian analysis, dT, $d\Delta v$ and dv are the respective uncertainties. W(CO) is the velocity integrated antenna temperature of the respective CO-spectra.

Due to the low signal-to-noise ratio no attempt to fit hyperfine components was made for the single spectra. For cloud 13 we integrated 4 spectra located next to each other close to the absorption peak at $l = 146°53'$, $b = 40°39'$ and obtained a spectrum which clearly shows the $F = 1 \rightarrow 0$ hyperfine component (see Fig. 1a). From this spectrum we get an intrinsic linewidth (full width at half maximum) of about 0.7 km s^{-1} and an optical depth for the strongest component of 0.6 ± 0.4.

The most striking result of our survey is that formaldehyde is detected at rather low CO emission peaks and is not detected at rather strong ones. Clouds 1 and 3 show the most striking discrepancy between the CO and H_2CO distribution at the polar clouds. For cloud 1 W(CO) is about 1.2 K km s^{-1} and for cloud 6 it is 4.4 K km s^{-1}. For cloud 1 we find a weak absorption line (see Fig. 1b) and for cloud 6 we see no line; the upper limit for the line temperature is about 8 mK (T_A).

For cloud 7 we obtained five spectra with signal located on a small cross centred on the most intense CO peak (see Fig. 1c, where we show the integrated profile from all five positions). The cloud is probably more extented than the area covered by the cross. Assuming that the cloud is optically thin for the 1_{10-11} H_2CO line and that the excitation temperature is 1.7 K the peak column density of formaldehyde for that line is $3.1\ 10^{12}$ cm^{-2} (cf. Few and Cohen, 1983). Using $N(H_2CO)/N(H_2) = 1.66\ 10^{-9}$ (Cohen et al., 1983) a column density of molecular hydrogen of $2.1\ 10^{21}$ cm^{-2} is implied. This value is uncertain by a factor of 10 because the value for $N(H_2CO)/N(H_2)$ is rather uncertain (see for example: Panagia and Thum, 1981; Sherwood, 1980). Adopting a distance of 100 pc (Magnani et al., 1985), the diameter of this cloud is 0.5 pc leading to an average density of molecular hydrogen of at least 1300 cm^{-3} and a mass of 7.3 solar masses.

Clouds 8 to 15 belong to the Ursa Major clouds described by de Vries et al. (1986). The CO emission peaks at cloud 8 and 10 show no H_2CO counterpart although their physical parameters are comparable to those of cloud 11 and 13, where lines are detected.

Cloud 13 is the most extended cloud of our sample. A map of $W(H_2CO)$

$$W(H_2CO) = -\int T_A \cdot dv$$

is shown in Fig. 2a. The extensions of the cloud are about 0°8 in longitude and 0°2 in latitude. The cloud was observed on a rectangular grid with 3′ spacing in longitude and 1′5 in latitude.

Adopting a distance of 100 pc for the cloud its linear dimensions are 1.4×0.35 pc. Assuming the same excitation temperature as for cloud 7 the column density of the 1_{10-11} formaldehyde line is $4.2\ 10^{12}$ cm^{-2} at the two peaks. From that an average density for molecular hydrogen of 2500 cm^{-3} follows. The total mass of this object is about 20 solar masses which is consistent within the errors with the mass deduced from CO observations (de Vries et al., (1986).

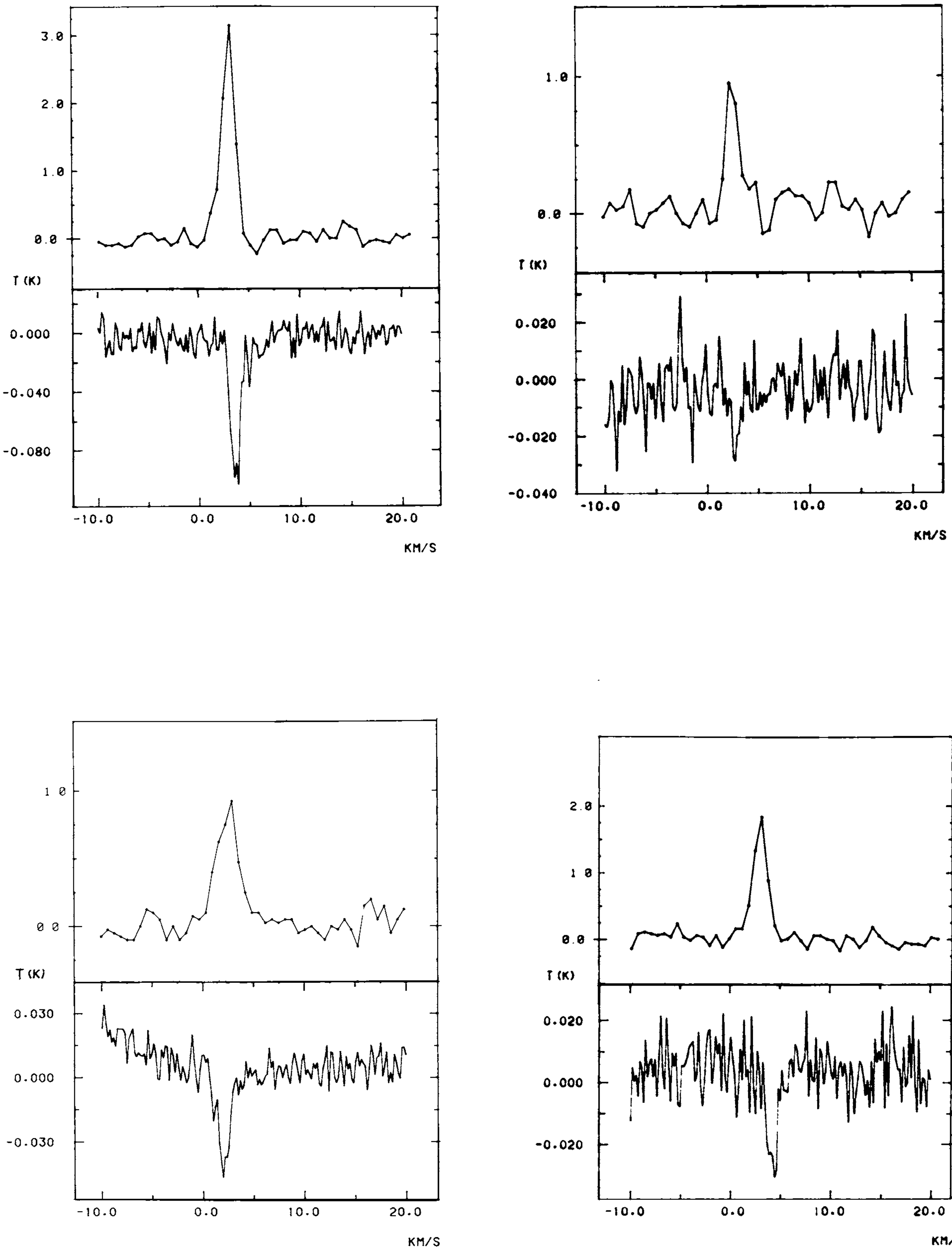

Fig. 1a–d. Some spectra for the clouds, in antenna temperature versus v_{LSR}. For comparison we show the CO spectra (the upper one) which lie nearest to the H_2CO spectra (the lower one). **a** Integrated spectrum for cloud 13. The center position is at $l = 146.^\circ8$, $b = 40.^\circ675$, the positions of the original spectra were separated by not more than 6′ (two times the beam of the Effelsberg telescope at 4.83 GHz). The line width, line depth and center velocity were almost the same for the different positions. The $F = 1 \rightarrow 0$ hyperfine component is clearly visible at $v = 5\,\mathrm{km\,s^{-1}}$. **b** Spectrum of cloud 1. **c** Integrated spectrum of all five positions of cloud 7, **d** Cloud 11

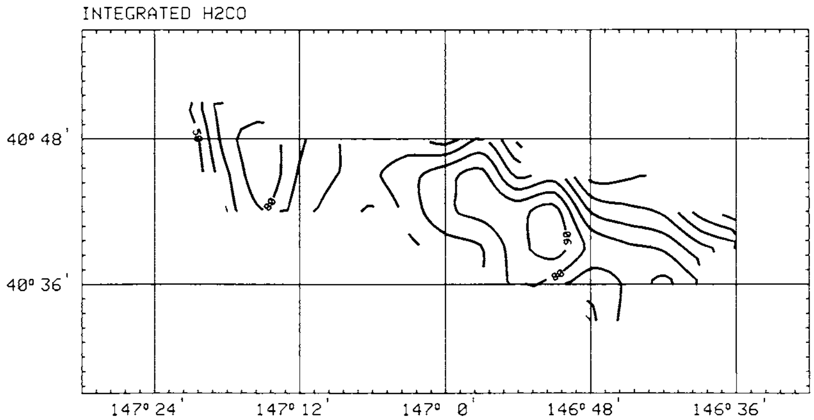

Fig. 2a. Integrated H_2CO map (T'_A). The step in contours is $10\,\mathrm{mk\,km\,s^{-1}}$, the numbers are in $\mathrm{mk\,km\,s^{-1}}$. The map is only complete between $l = 146°36'$ to $l = 147°20'$ and $b = 40°36'$ to $b = 40°48'$. The exact border is not yet known

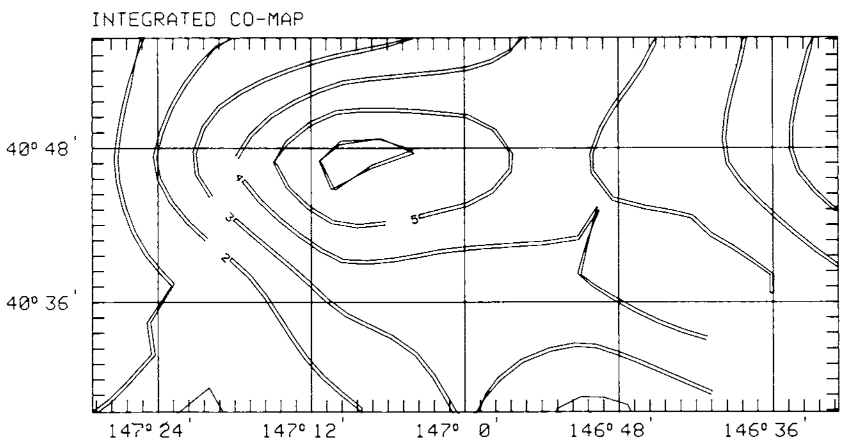

Fig. 2b. Map of W(CO), the step between contours is $1\,\mathrm{K\,km\,s^{-1}}$, the numbers at the contourlines are in $\mathrm{K\,km\,s^{-1}}$. A comparison with Fig. 2a shows that the distribution differs from that of $W(H_2CO)$. The maxima and minima in both maps show tendency to be anticorrelated

For comparison with the $W(H_2CO)$ distribution of cloud 13 we show in Fig. 2b a map of W(CO). Although the H_2CO-map is not complete, it is obvious that the $W(H_2CO)$ distribution is morphologically different from the W(CO) distribution. The CO peak at $l = 147°8'$, $b = 40°47'$ coincides with a saddle in the $W(H_2CO)$ distribution, the central H_2CO peak ($l = 146°52'$, $b = 40°40'$) falls close to a saddle in the W(CO) distribution and the H_2CO peak in the upper left ($l = 147°16'$, $b = 40°48'$) falls onto the large longitude edge of the W(CO) distribution. The situation is best described by saying that there appears to be an anticorrelation between the distribution of the $W(H_2CO)$ and the W(CO) peaks.

There are essentially four ways to explain this anticorrelation:

1. It is artificial and caused by differences in the telescope beams and sampling used for the CO and H_2CO observations. This can only be checked by new observations.

2. The variation of W(CO) with respect to $W(H_2CO)$ is essentially caused by a variation of the CO excitation temperature.

3. W(CO) and $W(H_2CO)$ are both direct measures of their respective column densities and interstellar chemistry somehow causes the two to vary in an anticorrelated way.

4. W(CO) is a direct measure of the H_2 column- and space-densities (Bloemen et al., 1986). Then the anticorrelation between H_2CO and the H_2 densities can only be explained by a positive correlation of the H_2CO excitation temperature and H_2 density implying space densities of the order of $10^5\,\mathrm{cm^{-3}}$ (Bastien et al., 1985).

The anticorrelation of the W(CO) and $W(H_2CO)$ peaks in cloud 13 is supplemented by the anticorrelation of the W(CO) and $W(H_2CO)$ values at the peaks of the other clouds. Obviously the above list of explanations applies here too, except that No. 1 is not very likely.

4. Conclusions

We surveyed the 15 strongest ^{12}CO peaks in the high latitude regions mapped by de Vries et al. (1986) and Heithausen et al. (1986) for the 6.2 cm line absorption of formaldehyde. Four of the corresponding CO-clouds have measurable amounts of H_2CO. We derive space densities of about 1000 to about $3000\,\mathrm{cm^{-3}}$ with an uncertainty of a factor 10 to 30. The masses are in the range of 4 to about 20 solar masses for the different clouds with the same uncertainty as the space densities. There is no clear limit of CO emission above which H_2CO is normally detected. On the contrary, some clouds with faint CO-emission are detected in formaldehyde and some clouds with strong CO-emission are not. Similarly, in our largest formaldehyde cloud (size $0\overset{\circ}{.}8 \cdot 0\overset{\circ}{.}2$) there is a tendency that large H_2CO absorption line depths are found to be minima in the CO-distribution and that maxima of the CO-distribution are associated with small H_2CO line depths. Possible explanations of this result range from problems with sampling and the beamsizes for the ^{12}CO and the H_2CO observations to variations in the abundances of the two molecules and variations of the kinetic temperature of ^{12}CO and the excitation temperature of H_2CO. In the latter case space densities in the order of $10^5\,cm^{-3}$ would be implied. Clearly more detailed CO observations or observations of molecules indicative of larger densities are needed to settle the exciting prospect of having densities of $10^5\,cm^{-3}$ in the high galactic latitude clouds.

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References

Bastien, P., Batrla, W., Henkel, C., Pauls, T., Walmsley, C.M., Wilson, T.L.: 1985, *Astron. Astrophys.* **146**, 86

Bloemen, J.B.G.M., Strong, A.W., Blitz, L. Cohen, R.S., Dame, T.M., Grabelsky, D.A., Hermsen, W., Lebrun, F., Mayer-Hasselwander, H.A., Thaddeus, P.: 1986, *Astron. Astrophys.* **154**, 25

Cohen, R.J., Matthews, N., Few, R.W., Booth, R.S.: 1983, *Monthly Notices Roy. Astron. Soc.* **203**, 1123

Cohen, R.S., Dame, T.M., Thaddeus, P.: 1986 *Astrophys. J. Suppl.* **60**, 695

Few, R.W., Cohen, R.J.: 1983, *Monthly Notices Roy. Astron. Soc.* **203**, 853

Goerigk, W., Mebold, U., Reif, K., Kalberla, P.M.W., Velden, L.: 1983, Astron. Astrophys. **120**, 63

Goerigk, W., Mebold, U.: 1986, *Astron. Astrophys.* **162**, 279

Heithausen, A., de Vries, H.W., Mebold, U.: 1986, in preparation

Keto, E.R., Myers, P.C.: 1986, *Astrophys. J.* **304**, 466

Kutner, M.L., Ulich, B.L.: 1981, *Astrophys. J.* **250**, 341

Low, F., Beintema, D.A., Gautier, F.N., Gillett, F.C., Beichman, C.A., Neugebauer, G., Young, E., Aumann, H.H., Boggers, N., Emerson, J.P., Habing, H.J., Hauser, M.G., Houck, J.R., Rowan-Robinson, M., Soifer, B.T., Walker, R.G., Wesselius, P.R.: 1984, *Astrophys. J. Letters* **278**, L19

Lynds, B.T.: 1962, *Astrophys. J. Suppl.* **7**, 1

Lynds, B.T.: 1965, *Astrophys. J. Suppl.* **12**, 163

Magnani, L., Blitz, L., Mundy, L.: 1985, *Astrophys. J.* **295**, 402

Mebold, U., Cernicharo, J., Velden, L., Reif, K., Crezelius, C. Goerigk, W.: 1985, *Astron. Astrophys.* **151**, 427

Panagia, N., Thum, C.: 1981, *Astron. Astrophys.* **98**, 295

Sherwood, W.: 1980, IAU *Symp.* **87**, 101

de Vries, H.W., Heithausen, A., Thaddeus, P.; 1986 submitted to *Astrophys. J.*

Wilson, T.L., Bieging, J., Downes, D., Gardner, F.F.: 1976, *Astron. Astrophys.* **51**, 303